



**QUEEN'S
UNIVERSITY
BELFAST**

A Novel Approach to Optimizing Hybrid Beamformer in MIMO Communication Systems (invited talk)

Molu, M., Xiao, P., & Fusco, V. (2017). *A Novel Approach to Optimizing Hybrid Beamformer in MIMO Communication Systems (invited talk)*. Paper presented at UK/Europe and China Workshop on MM-waves and THz Technologies , Liverpool, United Kingdom.

Document Version:
Other version

Queen's University Belfast - Research Portal:
[Link to publication record in Queen's University Belfast Research Portal](#)

Publisher rights
© 2017 The Author.

General rights
Copyright for the publications made accessible via the Queen's University Belfast Research Portal is retained by the author(s) and / or other copyright owners and it is a condition of accessing these publications that users recognise and abide by the legal requirements associated with these rights.

Take down policy
The Research Portal is Queen's institutional repository that provides access to Queen's research output. Every effort has been made to ensure that content in the Research Portal does not infringe any person's rights, or applicable UK laws. If you discover content in the Research Portal that you believe breaches copyright or violates any law, please contact openaccess@qub.ac.uk.

A Novel Approach to Optimizing Hybrid Beamformer in MIMO Communication Systems

Mehdi M. Molu, Pei Xiao, Vincent Fusco

Project: Informed RF for 5G and Beyond



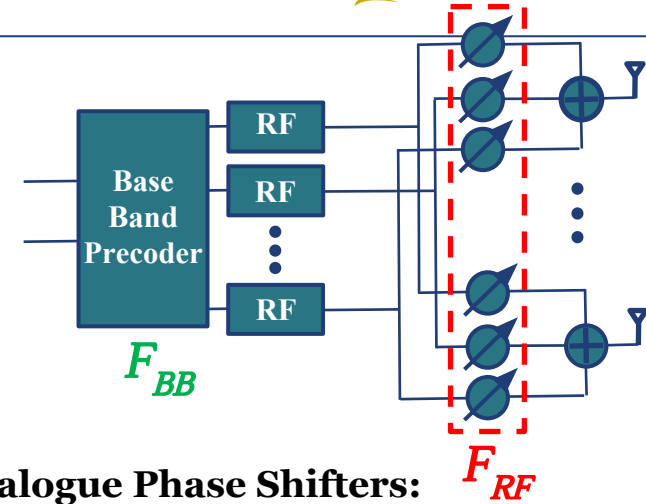
- ❑ Introduction and Problem Statement
- ❑ State of the Art Hybrid Beamformers
 - Massive MIMO
 - Millimetre Wave
- ❑ Proposed Solution
- ❑ Simulation Results
- ❑ Advantages and Disadvantages

Introduction and Problem Statement

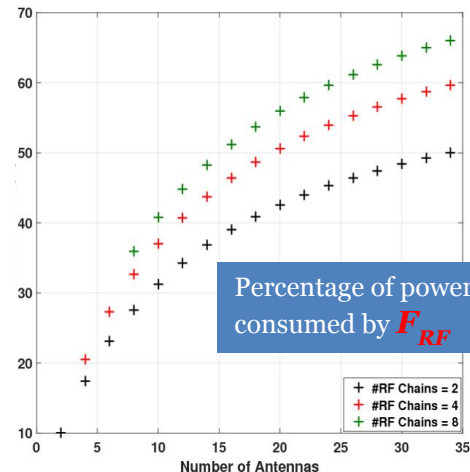
Massive MIMO and millimetre wave communications are two potential candidate technologies for 5G. In fact, the concept of mmWave is already deployed in several standards (IEEE 802.11ad, 802.15.3c).

Large number of antennas in the system forces us to use hybrid (Digital/Analogue) beamforming techniques to

- avoid high costs of RF chains and
- reduce hardware operating costs (e.g., insertion loss).



Component	Power (mW)	No. of Comp.
Base band precoder	≈ 200	1
RF chain	≈ 240	N_{RF}
LNA	≈ 20	N_{ant}
Phase shifter	≈ 20	$N_{RF}N_{ant}$



Digital vs Analogue Phase Shifters:

➤ Analogue

- Low Cost ✓
- Low insertion loss ✓

Digital

- Robust to noise on control lines ✓
- Ability to handle wider bandwidth ✓
- Higher insertion loss ✗

Existing Solutions

The idea is to maximise the transmission rate by properly designing \mathbf{F}_{RF} and \mathbf{F}_{BB} that is defined as follows:

$$C = \max_{\{\mathbf{F}_{RF}, \mathbf{F}_{BB}\}} \log \det(\mathbf{I} + \mathbf{R}_n^{-1} \mathbf{H} \mathbf{F}_{RF} \mathbf{F}_{BB} \mathbf{F}_{BB}^H \mathbf{F}_{RF}^H \mathbf{H}^H).$$

➤ Massive MIMO systems:

Using law of large number $\mathbf{H}^H \mathbf{H} \approx \mathbf{I}$. It can also be proved that $\mathbf{F}_{RF}^H \mathbf{F}_{RF} \approx \mathbf{I}$ and $\mathbf{F}_{BB} \approx \mathbf{I}$.
Given these assumptions, the values of \mathbf{F}_{RF} are calculated.

➤ Millimetre Wave Communication systems:

Common assumptions

- i. only limited number of rays arrive at the transceiver (spatially sparse channel).
- ii. AoD/AoD and corresponding gains are estimated.

Assuming $\mathbf{H} = \mathbf{U} \mathbf{S} \mathbf{V}^H$ and $\mathbf{F}_{RF}^{\text{opt}} \mathbf{F}_{BB}^{\text{opt}} = \mathbf{V}_1$, (near-optimal) \mathbf{F}_{RF} , \mathbf{F}_{BB} are calculated using the knowledge of \mathbf{H} , AoA/AoD and the gain per AoA/AoD.

Note: The existing solutions are (i) sub/near optimal and (ii) system and channel specific.

Proposed Hybrid Beamformer

Define transmission rate as follows

$$C = \max_{\{\mathbf{F}_{RF}, \mathbf{F}_{BB}, \mathbf{W}_{RF}, \mathbf{W}_{BB}\}} \log \det(\mathbf{I} + \mathbf{R}_n^{-1} \mathbf{W}_{BB} \mathbf{W}_{RF}^H \mathbf{H} \mathbf{F}_{RF} \mathbf{F}_{BB} \mathbf{F}_{BB}^H \mathbf{F}_{RF}^H \mathbf{H}^H \mathbf{W}_{RF}^H \mathbf{W}_{BB}^H).$$

Proposed Algorithm for Designing \mathbf{F}_{RF} (and \mathbf{W}_{RF}):

Assuming $\mathbf{y} = \mathbf{H} \mathbf{F}_{RF} \mathbf{F}_{BB} \mathbf{x} = \mathbf{U} \mathbf{L} \mathbf{V} \mathbf{F}_{RF} \mathbf{F}_{BB} \mathbf{x}$

➤ Step I: set $r_{21} = \text{sign}\{\text{Im}(\mathbf{v}_{11}^* \mathbf{v}_{21})\} |\mathbf{v}_{11}^* \mathbf{v}_{21}|$

➤ Step II: set $\delta_{21} = \text{Arccos}\left(\frac{\text{Re}(\mathbf{v}_{11}^* \mathbf{v}_{21})}{r_{21}}\right)$

$$\mathbf{V} = \begin{bmatrix} \mathbf{v}_{11} & \mathbf{v}_{12} & \mathbf{v}_{13} \\ \mathbf{v}_{21} & \mathbf{v}_{22} & \mathbf{v}_{23} \\ \mathbf{v}_{31} & \mathbf{v}_{32} & \mathbf{v}_{33} \end{bmatrix}$$

$$\mathbf{F}_{RF} = \exp(j \begin{bmatrix} 0 & 0 \\ \theta_{21} & \end{bmatrix})$$

Proposed Hybrid Beamformer

Define transmission rate as follows

$$C = \max_{\{\mathbf{F}_{RF}, \mathbf{F}_{BB}, \mathbf{W}_{RF}, \mathbf{W}_{BB}\}} \log \det(\mathbf{I} + \mathbf{R}_n^{-1} \mathbf{W}_{BB} \mathbf{W}_{RF}^H \mathbf{H} \mathbf{F}_{RF} \mathbf{F}_{BB} \mathbf{F}_{BB}^H \mathbf{F}_{RF}^H \mathbf{H}^H \mathbf{W}_{RF}^H \mathbf{W}_{BB}).$$

Proposed Algorithm for Designing \mathbf{F}_{RF} (and \mathbf{W}_{RF}):

Assuming $\mathbf{y} = \mathbf{H} \mathbf{F}_{RF} \mathbf{F}_{BB} \mathbf{x} = \mathbf{U} \mathbf{L} \mathbf{V} \mathbf{F}_{RF} \mathbf{F}_{BB} \mathbf{x}$

➤ Step I: set $r_{21} = \text{sign}\{\text{Im}(v_{11}^* v_{21})\} |v_{11}^* v_{21}|$

➤ Step II: set $\delta_{21} = \text{Arccos}\left(\frac{\text{Re}(v_{11}^* v_{21})}{r_{21}}\right)$

➤ Step III: if $(r_{21} > 0) \Rightarrow \theta_{21} = \delta_{21}$
 else $\theta_{21} = \delta_{21} + \pi$

$$\mathbf{V} = \begin{bmatrix} v_{11} & v_{12} & v_{13} \\ v_{21} & v_{22} & v_{23} \\ v_{31} & v_{32} & v_{33} \end{bmatrix}$$

$$\mathbf{F}_{RF} = \exp(j \begin{bmatrix} 0 & 0 \\ \theta_{21} & \end{bmatrix})$$

Proposed Hybrid Beamformer

Define transmission rate as follows

$$C = \max_{\{\mathbf{F}_{RF}, \mathbf{F}_{BB}, \mathbf{W}_{RF}, \mathbf{W}_{BB}\}} \log \det(\mathbf{I} + \mathbf{R}_n^{-1} \mathbf{W}_{BB} \mathbf{W}_{RF}^H \mathbf{H} \mathbf{F}_{RF} \mathbf{F}_{BB} \mathbf{F}_{BB}^H \mathbf{F}_{RF}^H \mathbf{H}^H \mathbf{W}_{RF}^H \mathbf{W}_{BB}^H).$$

Proposed Algorithm for Designing \mathbf{F}_{RF} (and \mathbf{W}_{RF}):

Assuming $\mathbf{y} = \mathbf{H} \mathbf{F}_{RF} \mathbf{F}_{BB} \mathbf{x} = \mathbf{U} \mathbf{L} \mathbf{V} \mathbf{F}_{RF} \mathbf{F}_{BB} \mathbf{x}$

➤ Step I: set $r_{31} = \text{sign}\{\text{Im}(\mathbf{v}_{11}^* \mathbf{v}_{31})\} |\mathbf{v}_{11}^* \mathbf{v}_{31}|$

➤ Step II: set $\delta_{31} = \text{Arccos}\left(\frac{\text{Re}(\mathbf{v}_{11}^* \mathbf{v}_{31})}{r_{31}}\right)$

$$\mathbf{V} = \begin{bmatrix} \boxed{\mathbf{v}_{11}} & \mathbf{v}_{12} & \mathbf{v}_{13} \\ \mathbf{v}_{21} & \mathbf{v}_{22} & \mathbf{v}_{23} \\ \boxed{\mathbf{v}_{31}} & \mathbf{v}_{32} & \mathbf{v}_{33} \end{bmatrix}$$

$$\mathbf{F}_{RF} = \exp(j \begin{bmatrix} 0 & 0 \\ \theta_{21} & \\ \theta_{31} & \end{bmatrix})$$

Proposed Hybrid Beamformer

Define transmission rate as follows

$$C = \max_{\{\mathbf{F}_{RF}, \mathbf{F}_{BB}, \mathbf{W}_{RF}, \mathbf{W}_{BB}\}} \log \det(\mathbf{I} + \mathbf{R}_n^{-1} \mathbf{W}_{BB} \mathbf{W}_{RF}^H \mathbf{H} \mathbf{F}_{RF} \mathbf{F}_{BB} \mathbf{F}_{BB}^H \mathbf{F}_{RF}^H \mathbf{H}^H \mathbf{W}_{RF}^H \mathbf{W}_{BB}).$$

Proposed Algorithm for Designing \mathbf{F}_{RF} (and \mathbf{W}_{RF}):

Assuming $\mathbf{y} = \mathbf{H} \mathbf{F}_{RF} \mathbf{F}_{BB} \mathbf{x} = \mathbf{U} \mathbf{L} \mathbf{V} \mathbf{F}_{RF} \mathbf{F}_{BB} \mathbf{x}$

➤ Step I: set $r_{31} = \text{sign}\{\text{Im}(\mathbf{v}_{11}^* \mathbf{v}_{31})\} |\mathbf{v}_{11}^* \mathbf{v}_{31}|$

➤ Step II: set $\delta_{31} = \text{Arccos}\left(\frac{\text{Re}(\mathbf{v}_{11}^* \mathbf{v}_{31})}{r_{31}}\right)$

➤ Step III: if $(r_{31} > 0) \Rightarrow \theta_{31} = \delta_{31}$
else $\theta_{31} = \delta_{31} + \pi$

$$\mathbf{V} = \begin{bmatrix} \boxed{\mathbf{v}_{11}} & \mathbf{v}_{12} & \mathbf{v}_{13} \\ \mathbf{v}_{21} & \mathbf{v}_{22} & \mathbf{v}_{23} \\ \boxed{\mathbf{v}_{31}} & \mathbf{v}_{32} & \mathbf{v}_{33} \end{bmatrix}$$

$$\mathbf{F}_{RF} = \exp(j \begin{bmatrix} 0 & 0 \\ \theta_{21} & \\ \theta_{31} & \end{bmatrix})$$

Proposed Hybrid Beamformer

Define transmission rate as follows

$$C = \max_{\{\mathbf{F}_{RF}, \mathbf{F}_{BB}, \mathbf{W}_{RF}, \mathbf{W}_{BB}\}} \log \det(\mathbf{I} + \mathbf{R}_n^{-1} \mathbf{W}_{BB} \mathbf{W}_{RF}^H \mathbf{H} \mathbf{F}_{RF} \mathbf{F}_{BB} \mathbf{F}_{BB}^H \mathbf{F}_{RF}^H \mathbf{H}^H \mathbf{W}_{RF}^H \mathbf{W}_{BB}).$$

Proposed Algorithm for Designing \mathbf{F}_{RF} (and \mathbf{W}_{RF}):

Assuming $\mathbf{y} = \mathbf{H} \mathbf{F}_{RF} \mathbf{F}_{BB} \mathbf{x} = \mathbf{U} \mathbf{L} \mathbf{V} \mathbf{F}_{RF} \mathbf{F}_{BB} \mathbf{x}$

➤ Step I: set $\mathbf{r}_{22} = \text{sign}\{\text{Im}(\mathbf{v}_{12}^* \mathbf{v}_{22})\} |\mathbf{v}_{12}^* \mathbf{v}_{22}|$

➤ Step II: set $\delta_{22} = \text{Arccos}\left(\frac{\text{Re}(\mathbf{v}_{12}^* \mathbf{v}_{22})}{r_{22}}\right)$

➤ Step III: if $(\mathbf{r}_{22} > 0) \Rightarrow \theta_{22} = \delta_{22}$
 else $\theta_{22} = \delta_{22} + \pi$

$$\mathbf{V} = \begin{bmatrix} \mathbf{v}_{11} & \mathbf{v}_{12} & \mathbf{v}_{13} \\ \mathbf{v}_{21} & \mathbf{v}_{22} & \mathbf{v}_{23} \\ \mathbf{v}_{31} & \mathbf{v}_{32} & \mathbf{v}_{33} \end{bmatrix}$$

$$\mathbf{F}_{RF} = \exp(j \begin{bmatrix} 0 & 0 \\ \theta_{21} & \theta_{22} \\ \theta_{31} & \end{bmatrix})$$

Proposed Hybrid Beamformer

Define transmission rate as follows

$$C = \max_{\{\mathbf{F}_{RF}, \mathbf{F}_{BB}, \mathbf{W}_{RF}, \mathbf{W}_{BB}\}} \log \det(\mathbf{I} + \mathbf{R}_n^{-1} \mathbf{W}_{BB} \mathbf{W}_{RF}^H \mathbf{H} \mathbf{F}_{RF} \mathbf{F}_{BB} \mathbf{F}_{BB}^H \mathbf{F}_{RF}^H \mathbf{H}^H \mathbf{W}_{RF}^H \mathbf{W}_{BB}^H).$$

Proposed Algorithm for Designing \mathbf{F}_{RF} (and \mathbf{W}_{RF}):

Assuming $\mathbf{y} = \mathbf{H} \mathbf{F}_{RF} \mathbf{F}_{BB} \mathbf{x} = \mathbf{U} \mathbf{L} \mathbf{V} \mathbf{F}_{RF} \mathbf{F}_{BB} \mathbf{x}$

➤ Step I: set $\mathbf{r}_{32} = \text{sign}\{\text{Im}(\mathbf{v}_{12}^* \mathbf{v}_{32})\} |\mathbf{v}_{12}^* \mathbf{v}_{32}|$

➤ Step II: set $\delta_{32} = \text{Arccos}\left(\frac{\text{Re}(\mathbf{v}_{12}^* \mathbf{v}_{32})}{r_{32}}\right)$

➤ Step III: if $(\mathbf{r}_{32} > 0) \Rightarrow \theta_{32} = \delta_{32}$
else $\theta_{32} = \delta_{32} + \pi$

$$\mathbf{V} = \begin{bmatrix} \mathbf{v}_{11} & \mathbf{v}_{12} & \mathbf{v}_{13} \\ \mathbf{v}_{21} & \mathbf{v}_{22} & \mathbf{v}_{23} \\ \mathbf{v}_{31} & \mathbf{v}_{32} & \mathbf{v}_{33} \end{bmatrix}$$

$$\mathbf{F}_{RF} = \exp(j \begin{bmatrix} 0 & 0 \\ \theta_{21} & \theta_{22} \\ \theta_{31} & \theta_{32} \end{bmatrix})$$

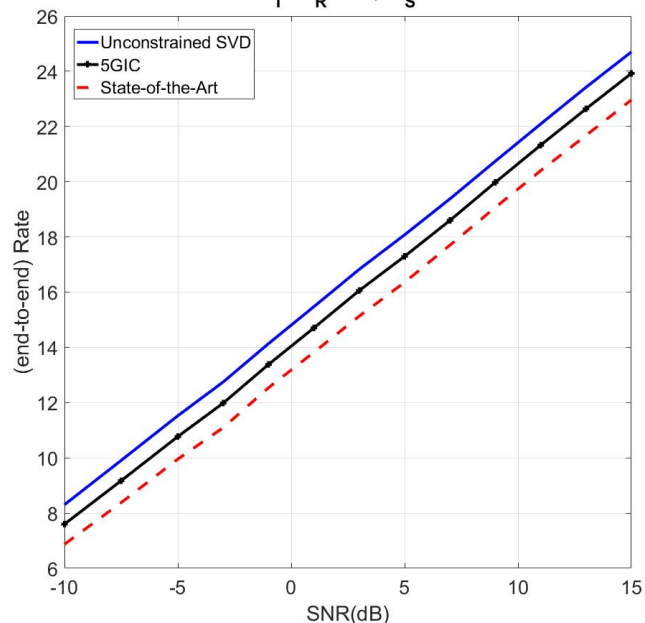
Simulation Results - II

Mutual Information the receiver:

$$C = \log \det(\mathbf{I} + \mathbf{R}_n^{-1} \mathbf{W}_{BB} \mathbf{W}_{RF} \mathbf{H} \mathbf{F}_{RF} \mathbf{F}_{BB} \mathbf{F}_{BB}^H \mathbf{F}_{RF}^H \mathbf{H}^H \mathbf{W}_{RF}^H \mathbf{W}_{BB}^H).$$

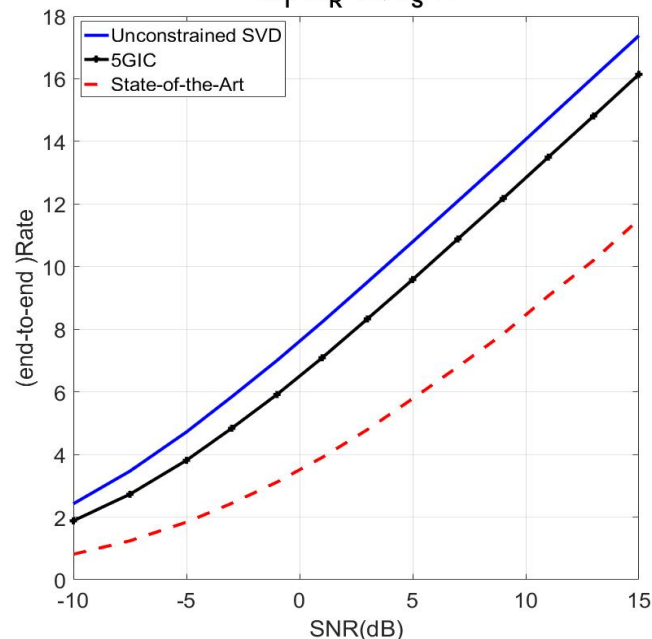
Sparse Channel

$m_T = m_R = 10, n_s = 2$



Rich Scattering Channel

$m_T = m_R = 10, n_s = 2$

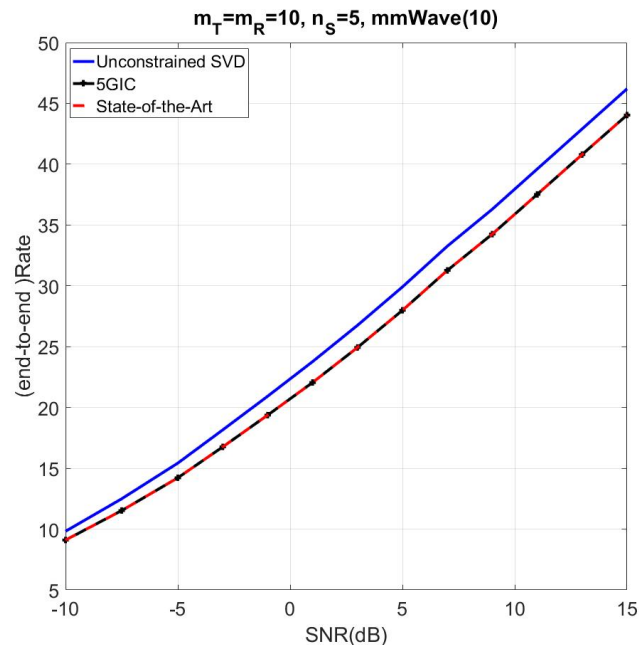


Simulation Results - II

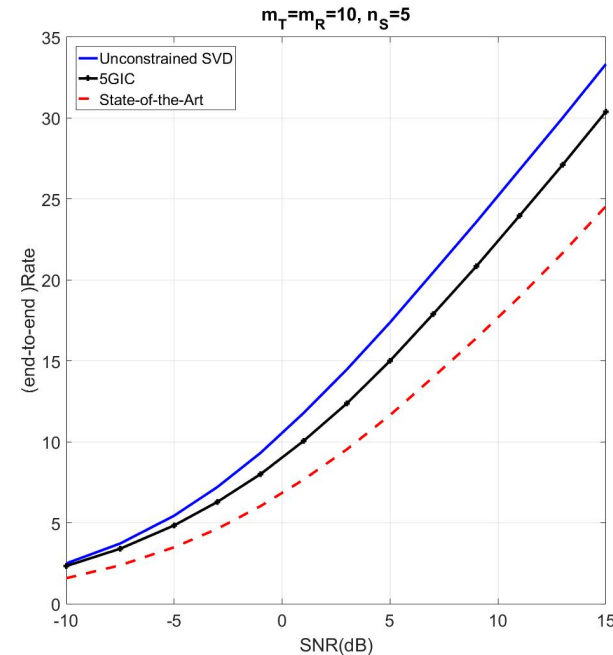
Mutual Information the receiver:

$$C = \log \det(\mathbf{I} + \mathbf{R}_n^{-1} \mathbf{W}_{BB} \mathbf{W}_{RF} \mathbf{H} \mathbf{F}_{RF} \mathbf{F}_{BB} \mathbf{F}_{BB}^H \mathbf{F}_{RF}^H \mathbf{H}^H \mathbf{W}_{RF}^H \mathbf{W}_{BB}^H).$$

Sparse Channel



Rich Scattering Channel

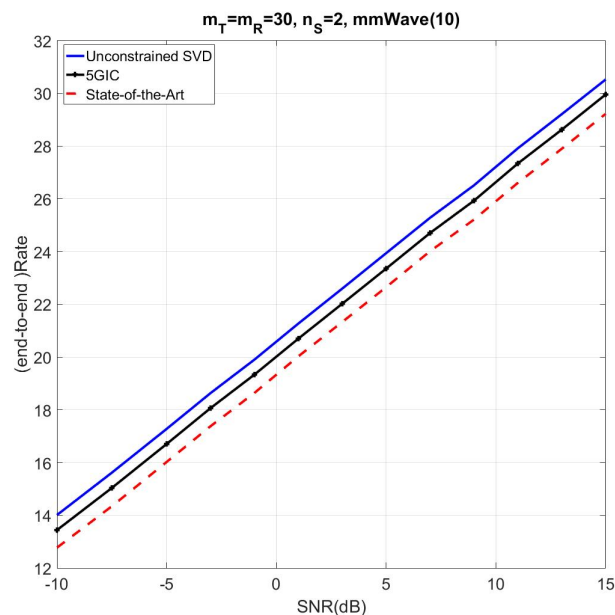


Simulation Results - II

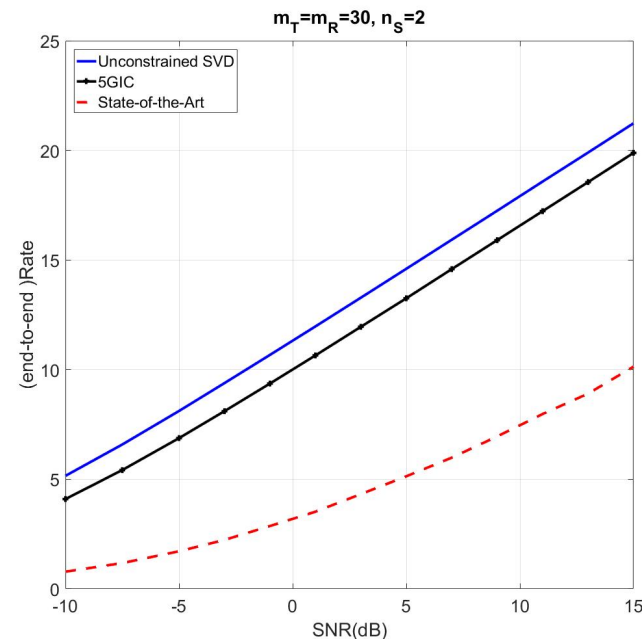
Mutual Information the receiver:

$$C = \log \det(\mathbf{I} + \mathbf{R}_n^{-1} \mathbf{W}_{BB} \mathbf{W}_{RF} \mathbf{H} \mathbf{F}_{RF} \mathbf{F}_{BB} \mathbf{F}_{BB}^H \mathbf{F}_{RF}^H \mathbf{H}^H \mathbf{W}_{RF}^H \mathbf{W}_{BB}^H).$$

Sparse Channel



Rich Scattering Channel



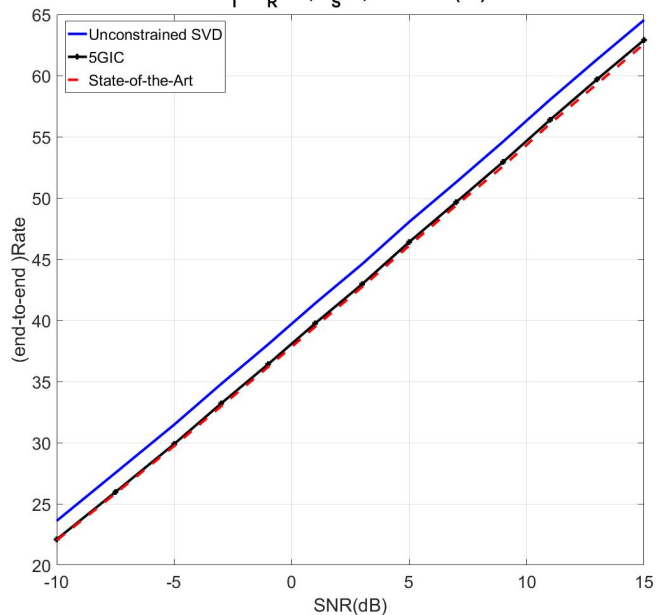
Simulation Results - II

Mutual Information the receiver:

$$C = \log \det(\mathbf{I} + \mathbf{R}_n^{-1} \mathbf{W}_{BB} \mathbf{W}_{RF} \mathbf{H} \mathbf{F}_{RF} \mathbf{F}_{BB} \mathbf{F}_{BB}^H \mathbf{F}_{RF}^H \mathbf{H}^H \mathbf{W}_{RF}^H \mathbf{W}_{BB}^H).$$

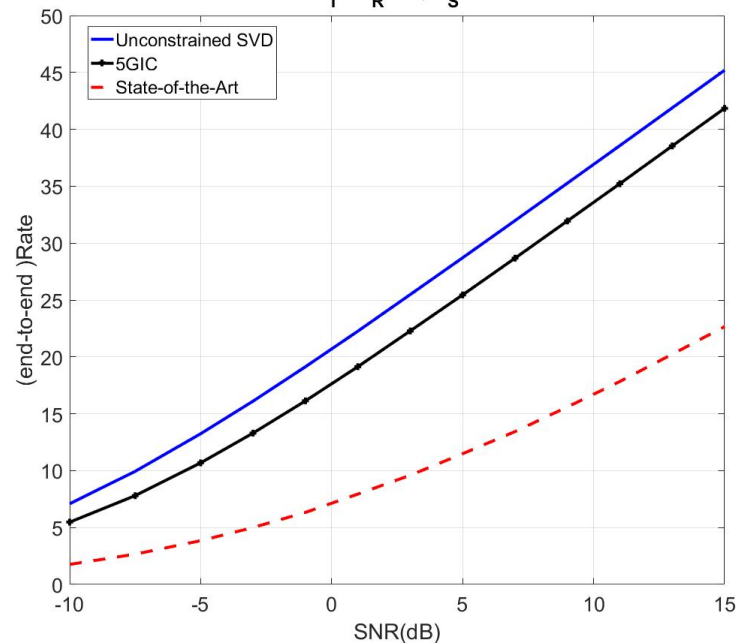
Sparse Channel

$m_T=m_R=30, n_S=5, \text{mmWave}(10)$



Rich Scattering Channel

$m_T=m_R=30, n_S=5$



Advantages and Disadvantages

Advantages:

- Phase Shifter values (\mathbf{F}_{RF}) are calculated using simple functions derived in this work.
- Only \mathbf{H} is required for implementing the algorithm . State of the art requires AoA/AoD and gain per scatterer.
- Algorithm can be applied to wide range of systems and channels. State of the art is system and/or channel specific.
- Low complexity and superior performance compared to state of the art.

Disadvantages:

- Any disadvantage of analogue phase shifters
- Anything else?

Thank You!